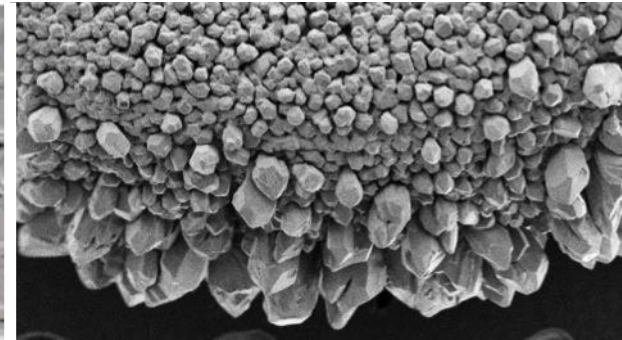


Exceptional service in the national interest



Energy Storage Safety

DOE OE Energy Storage Peer Review

September 17, 2014

SNL thanks Dr. Imre Gyuk for his decades of support of the SNL Energy Storage Program.

Sean J. Hearne

Manager, Energy Storage Technology & Systems



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

The Need for Energy Storage Safety Protocols

As an increasing number of energy storage systems are deployed, the risk of safety incidents increases.

Damage to Facilities



2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm

- There were two fires in a year at the Kahuku Wind Farm
- There was significant damage to the facility
- Capacitors in the power electronics are reported to be associated with the failure.

Impact to First Responders



2013 Storage Battery Fire, The Landing Mall, Port Angeles WA

- First responders were not aware of the best way to extinguish the fire,
- It reignited a week after it was thought to be extinguished.

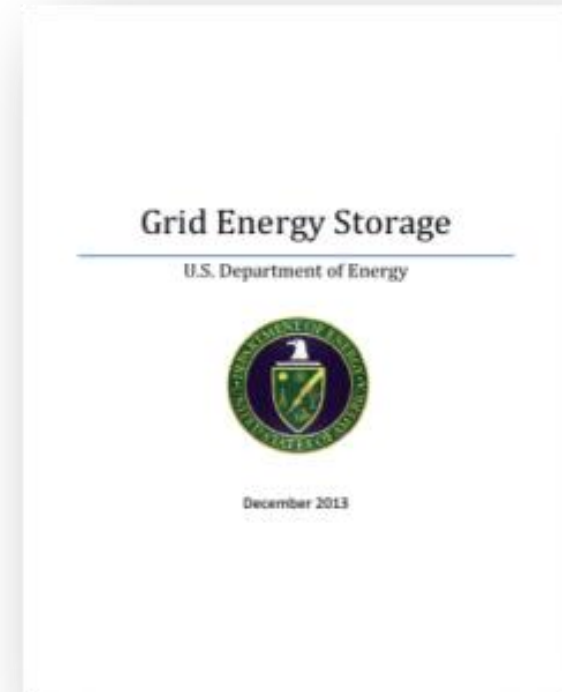
Challenges for Grid Energy Storage

During the commissioning hearings of Dr. Moniz to head US DOE, Senator Wyden requested a strategic plan for grid energy storage.

DOE Published the report in December 2013

Four Critical Challenges were identified

1. Cost Competitive Energy Storage Technologies
2. **Validated Reliability and Safety**
3. Equitable Regulatory Environment
4. Industry Acceptance



DOE OE Energy Storage Safety Workshop



- Share knowledge on safety validation, commissioning, and operations from the perspectives of a diverse cross section of the energy storage community
- Identify the current gaps in understanding, managing, standardizing and regulating safety in energy storage systems. This input will be the basis of the DOE OE Strategy for Energy Storage Safety.



Current Approach to Safety

The current approach is to test our way into safety¹

- Extensive destructive tests for safety (crush, burn, etc.)
- Large system (>1MWh) testing is difficult and generically not done.



Shortcoming of the current approach:

- Lacks capability to predict untested failure mechanisms with high reliability, i.e. can only design to prevent known failure modes.
- There are few published codes and standard for safety of storage systems.



¹ 'Power Grid Energy Storage Testing Part 1.' Blume, P.; Lindenmuth, K.; Murray, J. EE – Evaluation Engineering. Nov. 2012.

Workshop Outcome



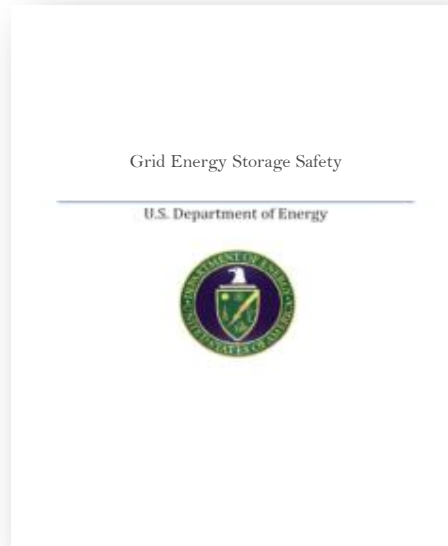
“Deployment of Energy Storage is ahead of codes, standards and regulations”

- Each deployment is currently treated as unique,
- This drives up cost,
- Increases installation and siting time,
- Causes uncertainty in available citing locations.

The areas that must be addressed are:

1. Developing standardized ***validation protocols***,
2. Increasing the knowledge base for ***incident preparedness*** and response,
3. Updating the ***codes, standards and regulations*** for energy storage safety.

DOE OE Strategic Plan on Safety



- **Gaps discussed and clarified**
 - Validation Protocols
 - First responder needs
 - Gaps in CSR's and resultant legal risks
- **Document completed and under final review by DOE OE**

DOE OE Strategic Plan on Safety

Lack of standardized validation protocol

- Science based testing protocols are needed.
- Validation protocols must link the materials and cell level to full systems integration into the grid.
- Knowledge gained in testing and analysis must be fed back to develop new safer materials.

Incident preparedness

- Fire control systems, e.g. fire suppression materials need to be identified for each storage technology
- First responders education
- Post-incident response

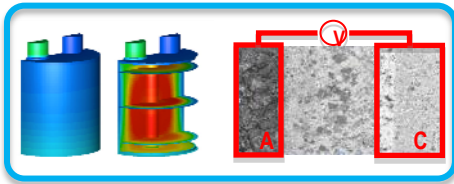
Incomplete and dispersed codes, standards and regulations (CSR)

- The CSR's for energy storage are dispersed throughout many sources (NEC, IEEE, UL, etc.). There is currently no central index of all the CSR's.
- The CSR's need continual updating due to rapid advances in storage technologies and new siting locations

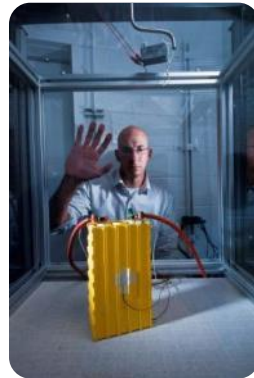
Sandia's Approach to Grid Storage Safety

Leverage existing leadership position in Safety Analysis of Vehicle Batteries

Simulations



Cell testing



Informing policy



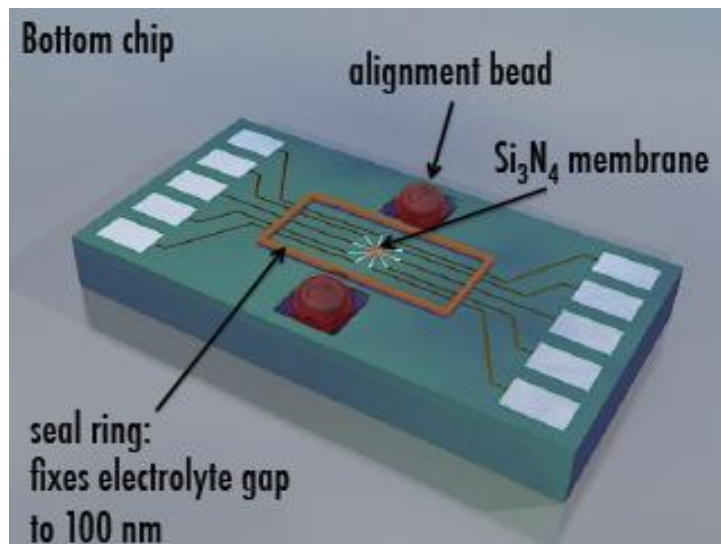
Large scale testing



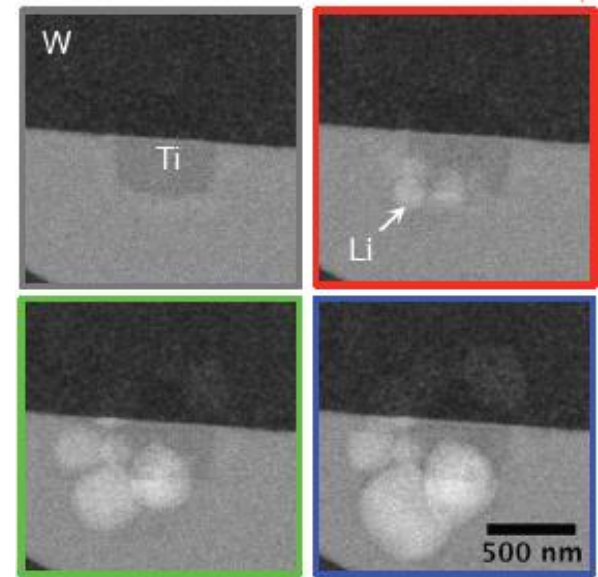
1. Develop a **science based** understanding of the processes that control and improve safety
2. Build **multi-scale models** for predicting incidences in storage systems to improved design
3. Analysis of cells through systems to **develop testing protocols**

Science Basis for Safety

Schematic of SNL fabricated TEM liquid cell



TEM images of Li growth during charging

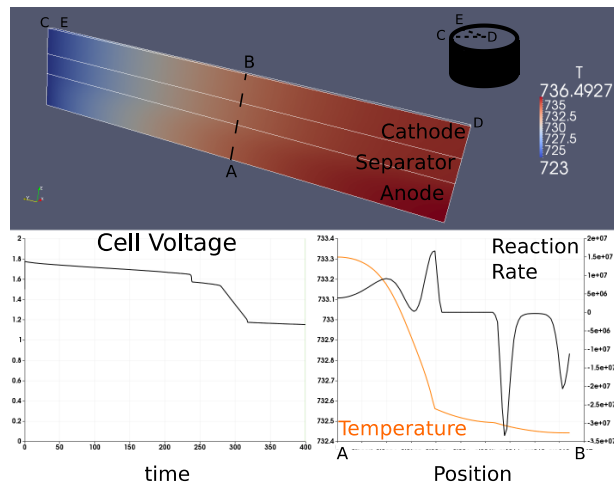


Electrochemistry inside a TEM to observe dendrite growth in flow batteries

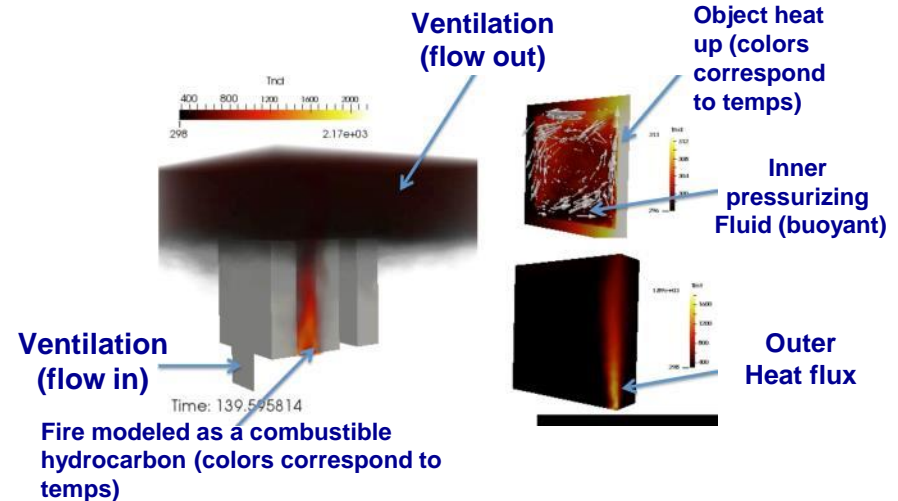
Modeling: Components through Systems

Modeling thermal events in cell

Model linking battery performance with thermal environment



Model of fire propagation between storage packs

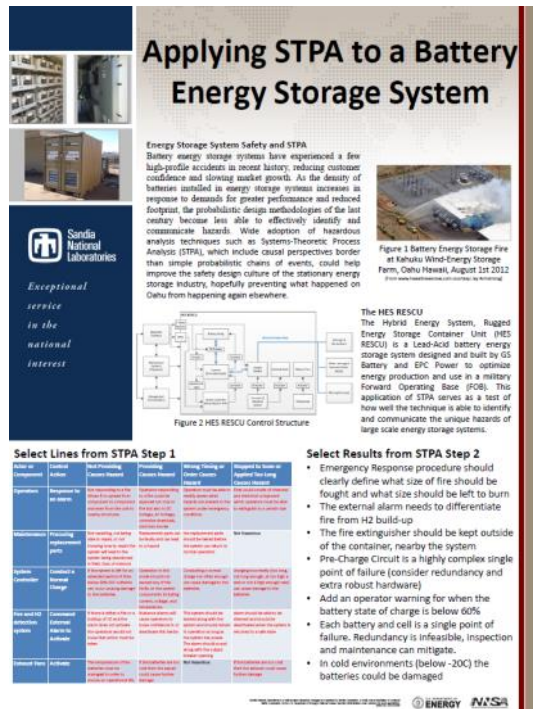


- Sandia has been using it's linked chemical / mechanical modeling capability to study failure in components through full systems.

Safety Protocol Development

Safety Engineering Protocols for ES

- **System-Theoretic Accident Model and Processes (STAMP)**



Application of Safety Codes and Standards

- NFPA 70 , NEC, Article 480 Storage Batteries
- NFPA 70E Article 320 Safety Requirements Related to Batteries and Battery Rooms
- IEEE Stationary Battery Committee Standards
- IEC 60812 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)
- IEC 61508 Functional Safety of Electrical /Electronic/ Programmable Electronic Safety-related Systems
- UL and other battery abuse testing standards

Cell Failure Propagation Protocol Development

- Developed stationary battery test procedure to determine if single cell failures will propagate to modules

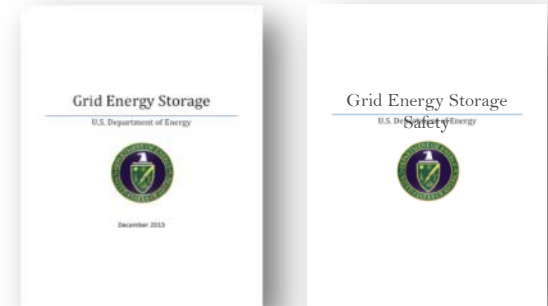
Project Status

- System Safety Analysis of TransPower GridSaver is in progress
- Waiting on laboratory availability for module abuse procedure validation

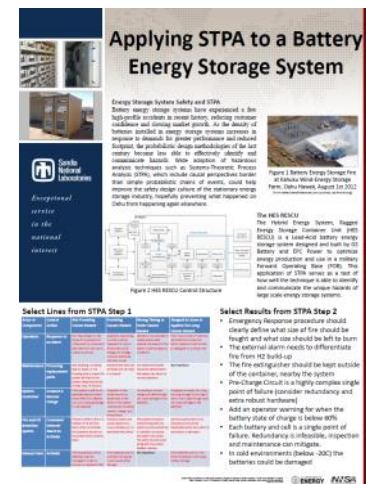
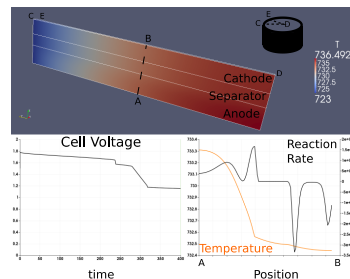
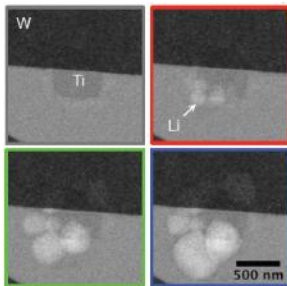
Summary

Community engaged in clarifying the challenges with safety validation

- Testing protocols
- Incident Response
- Limitation CSR



Sandia is leveraging its experience in vehicle battery safety to tackle the underlying mechanisms controlling safety to inform and develop validation protocols.



Backup Slides

Energy Storage System Requirement

- **High Performance (High value)**

Traditional focus

- High *Energy* and *Power* density
- Highly *efficient* device integration and operation (power electronics, control algorithms)

- **Low Cost**

- Low unit production cost (materials, design, manufacturing)
- Low Maintenance costs

- **High Reliability / Low Degradation rate**

- Long useful lifetime
- Predictable degradation rate
- Low frequency of stochastic failure (field failure)

- **Safe**

- No unanticipated failure modes
- No catastrophic failures
- Minimize collateral damage

Economic and Human Impacts: Point to Need for ES Safety/Reliability Codes and Standards, Policies

- **Fisker Karma/A123 Systems: Karma luxury PHEV**
 - December 2011 – *recall of first 239 vehicles* after NHTSA described it as a fire hazard
 - May 2012 – Fisker Karma fire *damaged home* of a new owner
 - August 2012 – another Karma caught fire. Fisker and A123 *recalled over 600 Karmas*
- **December 2008, Navy Advanced Seal Delivery System**
 - *Sub was not repaired* after explosion and battery fire
- **August 2012, Kahuku Wind Energy Storage Farm fires**
 - Damages caused by fire estimated to be *at least \$8M*
- **September 2011, Tokyo Electric Power company, NGK NaS battery fire**
 - NGK estimates losses associated with this incident to be *\$9.8B in 2012*
- **June 2006 Dell laptop battery fires**
 - Sony recall cost *exceeded \$300M*
- **September 2010: Cargo fire on UPS Boeing airplane, large quantity of Li ion batteries**
 - Both *crew members were killed* in crash
- **May 2012: Shenzhen, China EV taxi fire after high speed crash**
 - *Three passengers were killed*